Magnetic Anisotropy and its Microstructural Origins: Advances in Electron-Optical Characterization

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Electron microscopy investigations of epitaxially grown Sm-Co thin films show how atomic scale defects due to local compositional variations (polytypoids), observed only in high resolution electron microscopy, could explain their large coercivities by contributing to domain wall pinning. Unequivocal identification of such coercivity mechanisms requires advances in domain imaging techniques such as the novel differential phase contrast imaging technique currently being developed at the NCEM.

Background - Much of the recent enhancement in hard magnet performance has been achieved by developing materials with larger magnetocrystalline anisotropy. However, it is well known that even the best commercial hard magnets only achieve about 50% of the theoretical maximum energy product. In practical alloys, microstructural features play a key role and the effect of defects on domain wall pinning or nucleation of reverse domains are critical microstructural mechanisms that determine the coercivity of these materials. Hence, to understand coercivity mechanisms the physical, chemical and magnetic microstructure of these materials must be investigated at the highest level of resolution using the best electron optical imaging techniques available.

Accomplishment - Electron microscopy investigations of epitaxially grown Sm-Co thin films have revealed a microstructure containing polytypoids which could explain their large coercivities [1].

Sm-Co thin films synthesized at ANL with very high in-plane anisotropies have been extensively studied using transmission electron microscopy in conjunction with magnetic measurements. Two substrate orientations were investigated,

MgO(100)/Cr(100)/SmCo(11$\bar{2}$0) and
MgO(110)/Cr(211)/SmCo(1$\bar{1}$00)

In the former, the SmCo films show a bicrystalline microstructure, whereas in the latter a uniaxial structure is observed (figure 1). For the first time both microstructures were shown to consist of grains with a mixture of $SmCo_3$, Sm_2Co_7 and $SmCo_5$ polytypoids, i.e. compositionally stabilized structures observed only in high resolution images (figure 2). This microstructure suggests that pinning could occur either at the $SmCo_x$ polytypoids or at incoherent twins observed at grain boundaries.

To resolve such critical issues, it is important to be able to quantitatively image the domains, their interactions with microstructural features and their response to applied magnetic fields. We have recently developed and implemented a technique using a series of Lorentz images obtained at various beam tilts and subsequent processing to obtain quantitative vector plots of the in-plane induction [2]. The objective lens fields have also been accurately measured making it possible to apply well defined fields *in situ* in the microscope to observe domain motion and pinning mechanisms. A representative image from a complicated ripple structure in FeCo alloys, illustrating this development, is shown in figure 3.

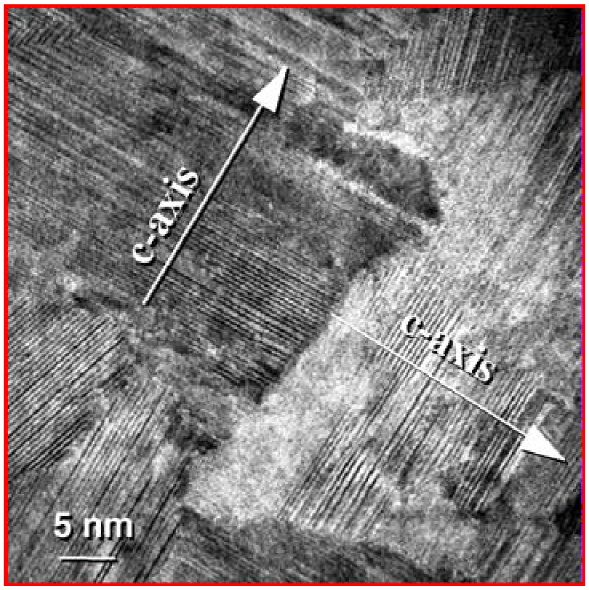

Fig. 1 Low magnification HRTEM images showing the microstructure of the as-grown (a) SmCo(1120) and SmCo(1100) thin films. The respective electron diffraction are shown in insets.

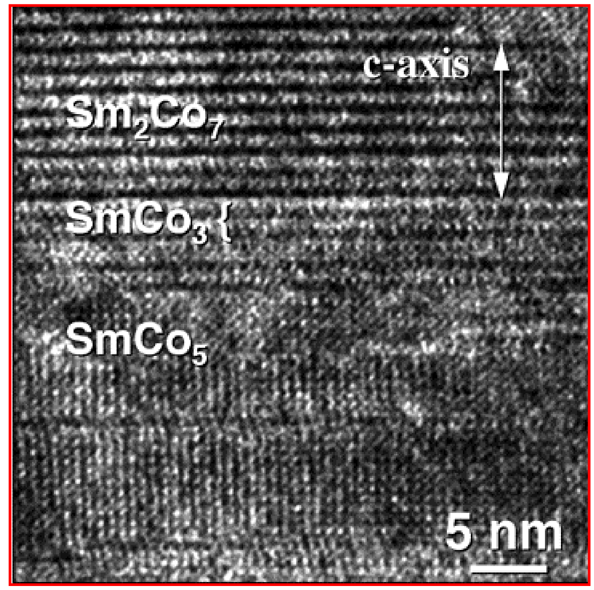

Fig.2 HRTEM image of a grain indicating the stacking disorder or formation of polytypoids along the c-axis.

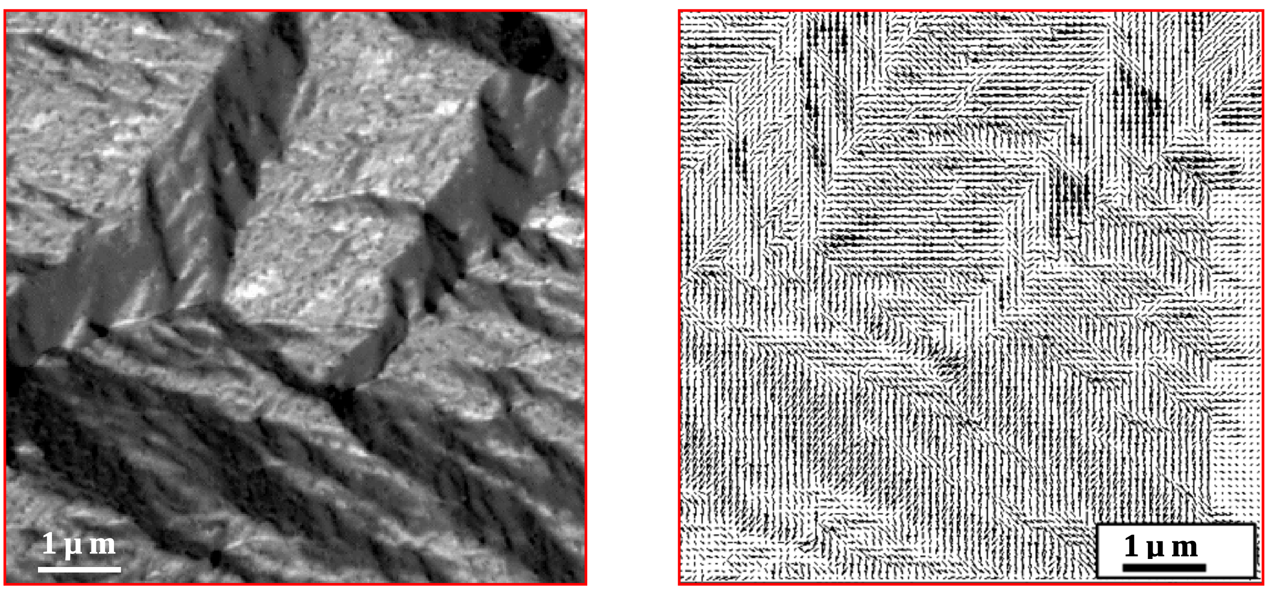

Fig. 3. Lorentz image (left) and quantitative vector representation (right) of the in-plane induction of a ripple structure in a Fe-Co alloy thin film. This plot is the result of processing a series of Lorentz images obtained with different tilts of the incident beam.

[1] M. Benaissa, K.M. Krishnan and E.E.Fullerton, *IEEE Trans. Mag.*, **34**, 1204 (1998)
[2] K. Verbist, E.C. Nelson, T.C. Anthony, J. A. Brug and K.M. Krishnan, *Proc. ICEM* 14, 503 (1998)